

*REDUCTIONS IN SHOCK FREQUENCY AND RESPONSE
EFFORT AS FACTORS IN REINFORCEMENT BY
TIMEOUT FROM AVOIDANCE*

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Rats' presses on one lever canceled shocks programmed after variable cycles, while presses on a second lever occasionally produced a 2-min timeout during which the shock-deletion schedule was suspended and its correlated stimuli removed. These concurrent schedules of avoidance and timeout were embedded in a multiple schedule whose components differed, within and across conditions, in terms of the programmed shock rate associated with the shock-deletion schedule. Analyses based on the generalized matching law suggest that the reduction in the response requirement correlated with termination of the avoidance schedule was a more important factor in the reinforcing effectiveness of timeout than was shock-frequency reduction, at least in 2 of 3 rats. After training in each condition, responding on the timeout lever was extinguished by withholding timeouts in both components over seven sessions. Resistance to extinction varied directly with the rates of both shock-frequency reduction and avoidance-response reduction experienced during training. Although reduction in response effort appeared to dominate shock-frequency reduction in the maintenance of responding, neither factor had a clear advantage in predicting the course of extinction.

Key words: timeout from avoidance, negative reinforcement, generalized matching law, resistance to extinction, response effort, shock-frequency reduction, lever press, rats

Several experiments have demonstrated that a signaled period of timeout from a shock avoidance contingency can function as a reinforcer in its own right. The most straightforward procedures arranged concurrent schedules in which avoidance and timeout were contingent on separate responses. Although early research with such procedures led Verhave (1962) to conclude that timeout is a weak reinforcer compared to food, other studies led to more positive results, indicating that timeout can maintain steady-state responding on fixed-ratio (Sidman, 1962), fixed-interval (Findley & Ames, 1965), progressive-ratio (Posner & Baron, 1981¹), variable-interval (Perone & Galizio, 1987), and variable-ratio (Galizio & Allen, 1991) schedules.

As a method for the analysis of negative reinforcement, the concurrent avoidance-timeout procedure circumvents several disadvantages of single free-operant avoidance schedules (cf. Perone & Galizio, 1987). Because avoidance has no obvious contiguous consequences, the nature of its reinforcement is unclear and open to contention. To complicate matters, avoidance procedures make it difficult to separate the rate or magnitude of the presumed reinforcer from the operations that establish its effectiveness: Reinforcement and motivational variables both are manipulated by way of the rate or intensity of the scheduled shocks. By comparison, a signaled timeout from avoidance has a clear locus in time and can be scheduled in essentially the same way as conventional positive reinforcers. Furthermore, variables that should establish timeout as a reinforcer, such as the parameters of the concurrent avoidance contingency, can be manipulated independently of the characteristics of the timeout per se (e.g., duration, accompanying stimuli, or delay). As a consequence, the concurrent avoidance-timeout procedure has the potential to facilitate direct comparisons between negative and positive reinforcement. Noteworthy in this regard are the results of recent studies showing that a variety of drugs

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¹ Posner, J., & Baron, A. (1981, May). *Progressive ratio schedules of positive and negative reinforcement*. Poster presented at the annual meeting of the Association for Behavior Analysis, Milwaukee, WI.

affect timeout-maintained behavior in essentially the same way as they affect food-maintained behavior (Galizio & Allen, 1991; Galizio, Journey, Royal, & Welker, 1990; Galizio & Perone, 1987; Galizio, Perone, & Spencer, 1986).

Although it is firmly established that timeout from avoidance can be an effective reinforcer, the specific variables that underlie its reinforcing function have not been determined. A timeout involves at least three changes in the experimental environment: removal of stimuli associated with the avoidance contingency, reduction in the rate of shock delivery, and suspension of the response requirement associated with the avoidance contingency. Perone and Galizio (1987) eliminated stimulus change as a possible source of reinforcement. After establishing stable responding in rats on a variable-interval (VI) schedule of timeout, they replaced the timeouts with "sham timeouts" during which the usual stimulus changes occurred (removal of general illumination, white noise, and the timeout lever) but the avoidance contingency remained in effect. Responding on the timeout lever extinguished, and reinstatement of the real timeouts led to rapid recovery.

The present experiment was designed to shed light on the contributions of reductions in shock frequency and avoidance responding to the reinforcing efficacy of timeout from avoidance. On concurrent schedules, rats' presses on one lever canceled shock deliveries programmed at variable intervals (de Villiers, 1972), while presses on a second lever occasionally removed the shock-deletion schedule and the stimuli correlated with it for 2 min. The concurrent schedules were embedded within a multiple schedule whose components differed, within and across conditions, in terms of the programmed shock rate associated with the shock-deletion schedule. By generating a range of shock rates and avoidance response rates, these manipulations allowed us to assess the sensitivity of responding on the timeout lever to the reductions of shock frequency and response effort afforded by the timeout periods. For this purpose we used the generalized matching equation (Baum, 1974):

$$(B_1/B_2) = k(r_1/r_2)^a,$$

where B_1 and B_2 are rates of responding on the timeout lever in the two components, and

r_1 and r_2 are the consequences of responding expressed in terms of either shock-frequency reduction (the difference between shock rates during time-in vs. timeout) or avoidance-response reduction (the difference between rates of responding on the avoidance lever during time-in vs. timeout). The constant k represents bias in the responding in one stimulus condition or the other, and a represents sensitivity to changes in the ratio of the putative reinforcement rates across the components. So that least squares linear regression could be used to determine the values of the constants, the equation was used in its logarithmic form:

$$\log(B_1/B_2) = a \log(r_1/r_2) + \log k,$$

where a is the slope and $\log k$ is the intercept of the linear function relating the logs of the response and reinforcer ratios.

As an additional test, after each condition we withheld timeout and measured the resistance to extinction of responding on the timeout lever. Research with food-maintained behavior has shown that resistance to extinction is directly related to the parameters of reinforcement experienced during training (e.g., Nevin, 1974, 1988). In a similar vein, we sought to determine whether the course of extinction of the timeout response is related to the shock rates or avoidance rates maintained during training.

METHOD

Subjects

Three male albino rats, 3 to 4 months old at the outset of training, were housed individually under a 12:12 hr reversed light/dark cycle with free access to food and water. Experimental sessions were conducted during the dark part of the cycle.

Apparatus

One custom-built operant chamber and two commercial chambers (Lehigh Valley Electronics) were used. The interiors were approximately 30 cm long, 21 cm high, and 19 cm deep. In each commercial chamber, the side walls and ceiling were constructed of Plexiglas, and the end walls were stainless steel. The floor consisted of stainless steel rods, 0.5 cm in diameter, spaced 1.9 cm apart, center to center. Illumination was provided by a 28-V

houcelight (No. 1820) mounted behind a sheet of white paper on a side wall. Two levers were centered 10 cm apart on the front wall, 9 cm above the grid floor. In the custom-built chamber, the rear wall, ceiling, and one side wall were constructed of clear Plexiglas, the other side wall of stainless steel, and the front wall of aluminum. The levers were 8.5 cm apart, 9.6 cm above the floor, and the floor rods were spaced 1.7 cm apart. General illumination was provided by a houselight at the top of the front wall. In all three chambers, the left lever (BRS/LVE, RRL-015) was retractable and the right was fixed in place. The levers required a force of approximately 0.3 N to operate. Grason-Stadler shock generators (E1064GS) could deliver scrambled 1-mA shocks lasting 0.5 s through the grid floors (but not the levers or walls). Each chamber was enclosed in a sound-attenuating box equipped with a fan for ventilation and a speaker for white noise. Control and recording operations were accomplished with microcomputers (Tandy, TRS-80 Models 4 and 4p) connected to the chambers by commercial interfaces (Alpha Products, Interfacer 80) and electromechanical equipment, using a software system described elsewhere (Perone, 1985).

Throughout the experiment, activation of the white noise generator and houselight signaled the onset of the session; these events were terminated at the end of the session as well as during the timeout periods. Avoidance responses produced a feedback stimulus consisting of 0.5-s offset of the white masking noise (except during shaping when the feedback duration was increased). Responses on the timeout lever produced an audible relay click in the commercial chambers, but responses in the custom-built chamber produced only the sound and feel of the lever's microswitch.

Preliminary Training

Avoidance. With the left lever retracted, the rat was trained to press the right lever using a shaping procedure based on one described by Baron (1991, pp. 181–182). The experimenter delivered or withheld shocks so that successive approximations to lever pressing were followed by a shock-free period and a feedback stimulus consisting of brief offset of the white noise. Initially, the shock-free periods were 60 s and the feedback was 1.5 s; these values were gradually reduced to 30 s

and 0.5 s over 2 to 6 hr. When the rat was consistently avoiding shock, the same procedure was used to establish responding on the left lever, with the right lever removed. Finally, control was transferred to a shock-postponement schedule (Sidman, 1953) in which each response delayed shock for 30 s (the response-shock or RS interval), but in the absence of responding shocks were delivered every 5 s (the shock-shock or SS interval). On alternate sessions, only the left or right lever was mounted in the chamber; the purpose was to facilitate responding on both levers so that the avoidance and timeout schedules would both be contacted when they were made available concurrently. Avoidance training was continued for 8 to 24 hr (4 to 12 sessions), until responding was well established on both levers.

Discrimination of time-in and timeout. In the next phase, a three-component multiple schedule was used to facilitate avoidance responding in the presence of two stimuli and its cessation in their absence. In two of the components, independent variable-cycle (VC) shock-deletion schedules (de Villiers, 1972) replaced the shock-postponement schedule. One of these components was accompanied by constant illumination of the houselight and the other by flashing illumination (0.5 s on, 0.5 s off). The VC schedule programmed shocks at irregular intervals (or cycles) averaging 30 s. Within each cycle, the first lever press canceled the shock that otherwise would have been delivered at the end; further responses had no scheduled consequence. The cycles were drawn from Fleshler and Hoffman's (1962) distribution, modified so that the minimum inter-shock interval was 5 s. During the third component—timeout—the houselight and white noise were turned off, and no shock-deletion schedule was programmed.

Each of the three components was presented four times per session. The 10-min presentations were arranged in irregular order, with the timeout component preceded and followed equally often by each of the two avoidance components. To facilitate extinction of avoidance responses during the timeout component, the component could not end within 1 min of a response. Perhaps because the stimuli accompanying timeout were the same as those before and after the sessions, this contingency was rarely contacted. As in the previous phase,

Table 1

Rates of avoidance responding, shock delivery, and timeout responding in each component of the multiple variable-cycle variable-cycle (VC) schedules. Also shown is the houselight (HL) stimulus (constant, C, or flashing, F) associated with each component. The conditions (pairs of components) are listed in order of presentation. Results are expressed as means (events per minute) and standard deviations (in parentheses) over the last five training sessions (Train) and all seven extinction sessions (Ext), except for responding on the timeout lever, which is shown on a session-by-session basis during extinction (E1, E2, etc.).

Rat	Condi- tion	VC (s)	HL	Avoidance rate		Shock rate		Timeout rate							
				Train	Ext	Train	Ext	Train	E1	E2	E3	E4	E5	E6	E7
G1	1	30	F	3.10 (0.26)	3.62 (0.59)	1.64 (0.15)	1.11 (0.26)	2.43 (0.17)	2.00	1.16	1.36	0.56	0.76	0.48	0.60
			C	2.08 (0.23)	2.60 (0.30)	0.78 (0.28)	0.41 (0.18)	1.85 (0.12)	2.36	0.60	0.76	0.56	0.28	0.16	0.16
	2	30	F	2.86 (0.54)	3.65 (0.51)	1.66 (0.24)	0.97 (0.16)	1.91 (0.26)	1.72	1.60	1.08	1.08	0.44	0.76	0.68
			C	1.42 (0.35)	2.03 (0.40)	0.34 (0.10)	0.28 (0.14)	1.29 (0.10)	1.12	1.04	0.60	0.64	0.56	0.24	0.44
	3	15	F	6.78 (1.77)	7.90 (1.61)	2.36 (0.54)	1.73 (0.48)	2.89 (0.33)	2.72	1.64	1.92	2.16	1.20	1.08	0.92
			C	2.63 (0.97)	2.54 (0.91)	0.29 (0.16)	0.18 (0.13)	1.49 (0.28)	0.64	0.56	0.44	0.20	0.20	0.28	0.24
	4	15	F	6.85 (0.88)	7.85 (2.44)	2.54 (0.89)	2.17 (1.22)	3.23 (0.26)	2.45	2.16	1.36	1.00	1.04	0.56	0.52
			C	3.64 (0.60)	3.25 (1.34)	1.34 (1.28)	0.78 (0.90)	2.22 (0.06)	0.75	0.84	1.32	0.52	0.92	0.44	0.44
	5	120	F	7.06 (3.15)	6.83 (2.49)	0.07 (0.05)	0.09 (0.09)	2.80 (0.92)	1.28	0.72	0.76	0.36	0.44	1.00	0.28
			C	9.78 (4.11)	10.03 (2.74)	1.34 (0.88)	0.97 (0.33)	3.64 (0.76)	3.04	1.84	1.36	1.08	1.32	1.68	0.92
G5	1	30	C	4.16 (1.48)	5.50 (1.83)	0.76 (0.20)	0.78 (0.18)	1.99 (0.36)	1.64	0.88	0.12	0.16	0.28	0.16	0.52
			F	4.48 (1.32)	5.39 (1.68)	0.24 (0.05)	0.27 (0.14)	2.11 (0.32)	1.80	0.88	0.24	0.28	0.36	0.00	0.68
	2	30	C	4.17 (0.35)	7.79 (0.67)	0.87 (0.05)	0.53 (0.11)	1.91 (0.27)	2.24	0.72	0.80	0.48	0.68	0.36	0.44
			F	4.14 (1.19)	5.95 (1.26)	0.08 (0.06)	0.05 (0.04)	2.03 (0.43)	1.76	0.68	0.40	0.24	0.44	0.12	0.28
	3	15	C	6.42 (1.23)	7.36 (1.19)	1.75 (0.26)	1.75 (0.22)	2.40 (0.24)	2.04	1.00	0.92	0.96	0.56	0.84	0.72
			F	4.77 (2.33)	3.14 (0.49)	0.06 (0.05)	0.16 (0.07)	1.90 (0.57)	1.28	0.64	0.72	0.48	0.28	0.32	0.08
	4	15	C	5.58 (1.07)	7.21 (1.35)	1.89 (0.19)	1.53 (0.27)	2.54 (0.37)	1.16	0.72	0.60	0.80	0.28	0.56	0.76
			F	3.49 (1.30)	5.67 (1.19)	0.38 (0.11)	0.18 (0.09)	1.54 (0.34)	0.72	0.48	0.88	0.16	0.32	0.56	0.12
	5	120	C	0.90 (0.33)	1.40 (0.0)	0.18 (0.04)	0.18 (0.04)	1.08 (0.16)	1.00	0.36	0.16	0.20	0.04	0.48	0.08
			F	2.20 (0.36)	2.90 (0.37)	2.42 (0.22)	2.10 (0.07)	1.88 (0.16)	1.28	0.80	0.80	0.16	0.44	0.36	0.44
G7	1	15	C	11.38 (2.80)	13.56 (0.94)	0.97 (0.17)	0.63 (0.08)	1.77 (0.39)	1.00	0.80	0.36	0.24	0.24	0.08	0.24
			F	10.29 (4.35)	9.91 (1.66)	0.23 (0.15)	0.14 (0.04)	1.98 (0.43)	1.68	1.24	0.64	0.08	0.52	0.36	0.16
	2	15	C	18.26 (0.71)	10.98 (2.70)	0.40 (0.11)	0.87 (0.35)	1.47 (0.11)	0.96	0.60	0.60	0.44	0.68	0.68	0.48
			F	15.96 (2.02)	8.38 (1.97)	0.05 (0.03)	0.07 (0.07)	2.17 (0.42)	1.40	0.72	0.64	0.72	0.32	0.44	0.20
	3	30	C	6.34 (1.46)	4.66 (1.33)	0.28 (0.09)	0.59 (0.09)	2.54 (0.23)	1.76	0.88	0.92	0.80	0.52	0.20	0.40
			F	5.68 (1.72)	3.19 (1.54)	0.10 (0.07)	0.17 (0.07)	2.80 (0.25)	1.16	1.08	0.68	0.40	0.72	0.24	0.12

Table 1 (Continued)

Rat	Condi- tion	VC (s)	HL	Avoidance rate		Shock rate		Timeout rate							
				Train	Ext	Train	Ext	Train	E1	E2	E3	E4	E5	E6	E7
	4	30	C	4.22 (1.66)	3.58 (1.47)	0.62 (0.11)	0.83 (0.20)	2.82 (0.31)	1.48	1.04	1.00	0.48	0.88	0.60	0.56
		60	F	2.30 (1.23)	3.03 (2.04)	0.43 (0.13)	0.40 (0.09)	2.17 (0.18)	1.32	0.80	0.64	0.60	0.76	0.56	0.44
	5	120	C	5.68 (2.76)	3.71 (1.84)	0.06 (0.03)	0.11 (0.03)	2.73 (0.36)	1.04	0.32	0.68	0.48	0.28	0.28	0.28
		15	F	8.70 (1.87)	7.10 (1.92)	1.22 (0.32)	1.29 (0.19)	2.19 (0.23)	1.32	0.68	0.84	0.64	0.64	0.68	0.56

the left and right levers were used on alternate days. Multiple-schedule training was continued for 10 to 37 sessions, until fewer than 5% of the total responses occurred during the timeout component.

For Rat G1, whose avoidance proficiency was poor, an SS schedule was added to the VC schedules starting with the 27th session. If a cycle ended with a shock delivery, shocks continued to be delivered every 5 s until a response terminated the SS timer and began the next cycle. A second response was required to cancel the shock scheduled for that cycle. The SS schedule remained in effect throughout the experiment.

Response-dependent timeout. In the next phase, both levers were available concurrently. The avoidance lever, on the right, was always present in the chamber. As before, pressing the avoidance lever deleted shocks and produced 0.5-s offset of white noise. The timeout lever, on the left, was inserted at the start of the session and retracted at the end. Pressing it produced timeouts during which the houselight and white noise were turned off, the shock-deletion schedule was suspended, and the timeout lever was retracted. Although the avoidance lever remained in the chamber, the rats rarely pressed it during a timeout, and these responses had no effect (i.e., they did not prolong the timeouts as they had during discrimination training). The concurrent schedules of avoidance and timeout were embedded within a multiple schedule with alternating components accompanied by flashing and constant illumination of the houselight. There were five presentations each of the constant and flashing components, each lasting 5 min (exclusive of timeout periods, described below). An independent VC 30-s shock-deletion schedule was programmed on the avoidance lever in each component.

Initially, each press of the timeout lever produced a 5-min timeout. Over five to eight sessions, the duration of the timeout was reduced to 2 min and the timeout schedule was changed to a VI (Fleshler & Hoffman, 1962) with the mean interval gradually increased from 15 s to a terminal value of 45 s. Training with the VI 45-s schedule continued for another 10 sessions. By the end of preliminary training, all 3 rats responded on both the avoidance and timeout levers. The response rates did not differ across the flashing- and constant-house-light components, although rates on the timeout lever generally were lower than rates on the avoidance lever.

Procedure

In the experimental conditions, as in the last phase of preliminary training, a two-component multiple schedule was in effect. The components lasted 5 min, exclusive of timeout periods, and sessions lasted until each was presented five times. Thus, as in previous research (Perone & Galizio, 1987, Experiment 1), the procedure held constant the amount of exposure to the contingencies during time-in (a total of 25 min per component), regardless of the frequency of the timeouts. Each condition consisted of a training phase, in which 2-min timeouts were available on a VI 45-s schedule, and an extinction phase, during which responses on the timeout lever had no consequence (but responses on the avoidance lever continued to delete shocks). The last five training sessions and the seven test (extinction) sessions were conducted on consecutive days; otherwise sessions normally were conducted 6 days per week.

In each condition, the multiple-schedule components differed in terms of the scheduled shock rate during time-in. Table 1 shows the mean cycles (in seconds) of the VC shock-

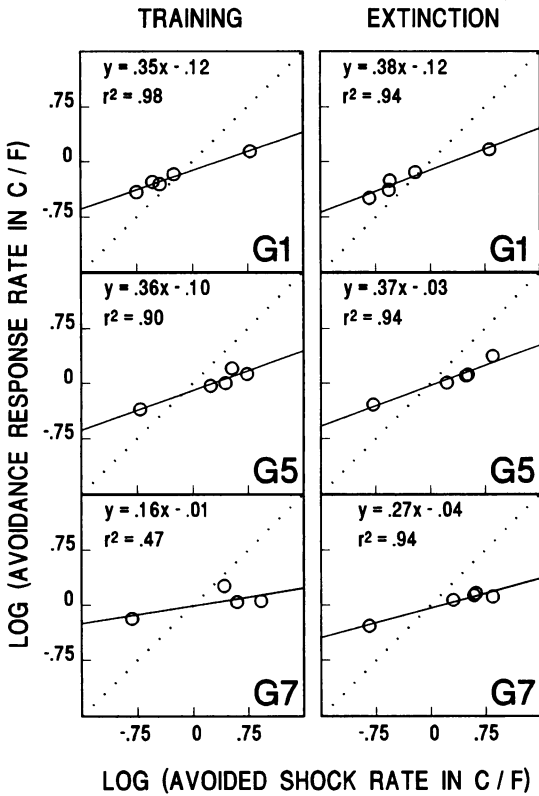


Fig. 1. The ratio of response rates on the avoidance lever in the constant-houselight (C) and flashing-houselight (F) components plotted against the ratio of avoided shock rates. In each panel, the dotted line represents ideal matching and the solid line the least squares regression line fitted to the data; also shown is the formula of the line and the proportion of explained variance (r^2). Data are the means of the last five training sessions (left panels) or the means of the seven extinction sessions (right) in each of the five conditions. Some panels appear to have fewer than five data points because of overlap.

deletion schedules in the two components. The component with the shorter intershock interval was signaled by the same stimulus throughout the first four conditions (flashing houselight for Rat G1, constant houselight for G5 and G7). In the fifth condition, the stimuli were reversed (e.g., constant houselight signaled the component with the shorter mean cycle for Rat G1). The order of the first four conditions for Rats G1 and G5 was opposite of that for G7.

Because previous work in our laboratory indicated that responding on these procedures tends to stabilize within about 20 sessions, the training phase was fixed at 25 days, with the last 5 days considered representative of steady-state behavior (i.e., a fixed-time stability cri-

terion was used; Sidman, 1960). This plan also ensured that the amount of training was equivalent across conditions. In a few cases, however, the training phase was extended. The final condition of Rats G1 and G7 lasted an extra session by mistake. Rat G7's second and third conditions were extended 12 and 10 sessions, respectively, to allow the animal to recover from failures of the shock delivery system.

RESULTS

Avoidance

Table 1 summarizes the avoidance response rates and received shock rates in the multiple-schedule components of each condition. For Rat G1, whose schedules included an SS contingency, the received shock rate includes the SS shocks. For all 3 rats, stable rates of avoidance responding were maintained in both the training and extinction phases. The response rates usually were higher in the VC component with the shorter mean cycle, and the received shock rates were consistently higher. For 2 of the rats, avoidance response rates changed when the concurrent schedule of timeout was replaced with extinction; Rat G5's rates tended to increase and G7's tended to decrease.

Figure 1 shows rates on the avoidance lever in relation to the overall rates of shock-frequency reduction that resulted from responding on the VC schedules during time-in. Shock-frequency reduction was calculated by counting the number of canceled shocks that otherwise would have been delivered by the VC schedule. In Rat G1's case, then, the potential rate of SS shocks (12 per minute) was disregarded (for a justification, see DeWaard, Galizio, & Baron, 1979, p. 406). The figure shows the ratio of response rates across the multiple-schedule components (rates in the constant houselight divided by rates in the flashing houselight) plotted against the ratio of the avoided shock rates in the two components on logarithmic axes. Also shown are least squares regression lines. In general, the lines fit the data well. Coefficients of determination (r^2) are at least .90 in five of six cases. In the remaining case, Rat G7's training results, the lower proportion of explained variance may be attributed to the narrow range of response ratios; still, the fit is good, with all but one of the data points falling on the regression line.

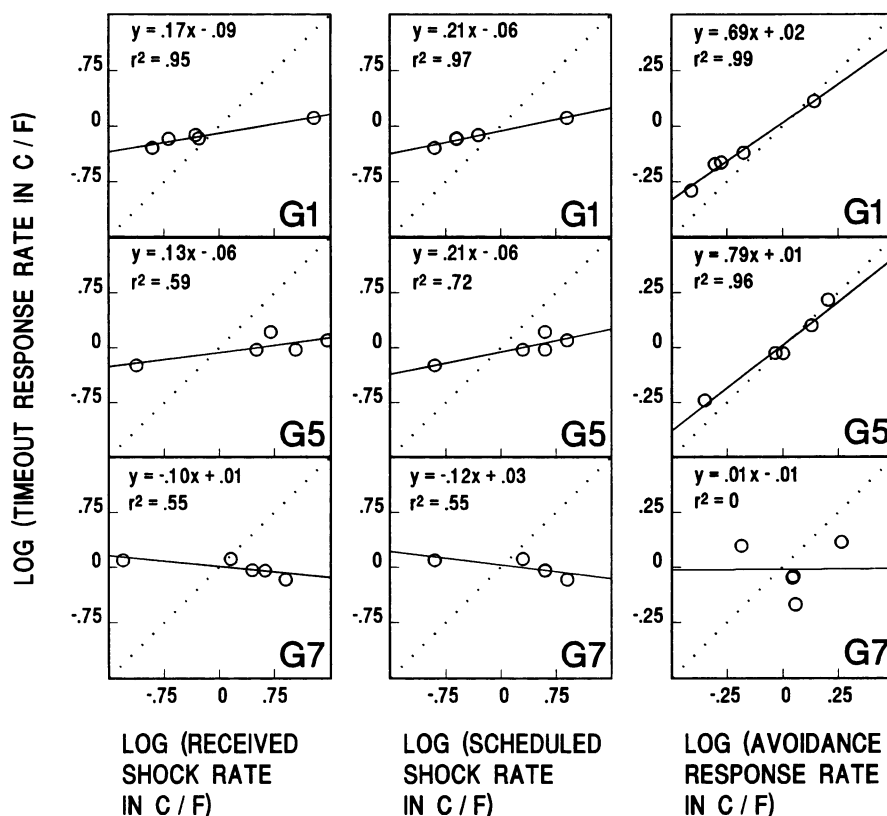


Fig. 2. The ratio of response rates on the timeout lever in the constant-houselight (C) and flashing-houselight (F) components plotted against the ratio of received shock rates (left panels), scheduled shock rates (center), and avoidance response rates (right; note the change in scale in these panels). Data are means of the last five training sessions in each condition. Other details as in Figure 1.

In most cases the slopes of the lines, representing the sensitivity parameter of the generalized matching law (Baum, 1974), are positive but considerably less than one. Thus, although avoidance responding varied directly with shock-frequency reduction, the sensitivity of behavior to this factor was well below matching. The relation between responding and shock-frequency reduction was about the same in the training and extinction phases. During training sessions, responding on the avoidance lever was frequently interrupted by 2-min timeout periods as well as by bouts of responding on the timeout lever. There were no timeouts in the extinction phase, of course, but responding on the timeout lever continued, although at rates that diminished over the seven sessions (see Table 1).

Maintenance of Timeout Responding

The main purpose of this experiment was to shed light on the factors responsible for the

reinforcing effect of timeout from avoidance. To this end, we assessed the sensitivity of responding on the timeout lever to three potential sources of reinforcement, two involving shock-frequency reduction and one involving the reduction in response effort afforded by the timeout periods. In each case, the focus is on the environmental change that occurred when responding on the timeout lever suspended the ongoing avoidance contingency and thus eliminated the prevailing rate of received shocks, the programmed rate of potential shocks, and the requirement for responding on the avoidance lever. The analyses are shown in Figure 2, using the same basic format as Figure 1. The data are from the last five training sessions in each condition; there is no analysis of the extinction sessions because timeouts were not scheduled during these sessions and therefore responding on the timeout lever was not stable.

The left and center panels of Figure 2 show the relation between responding and the two

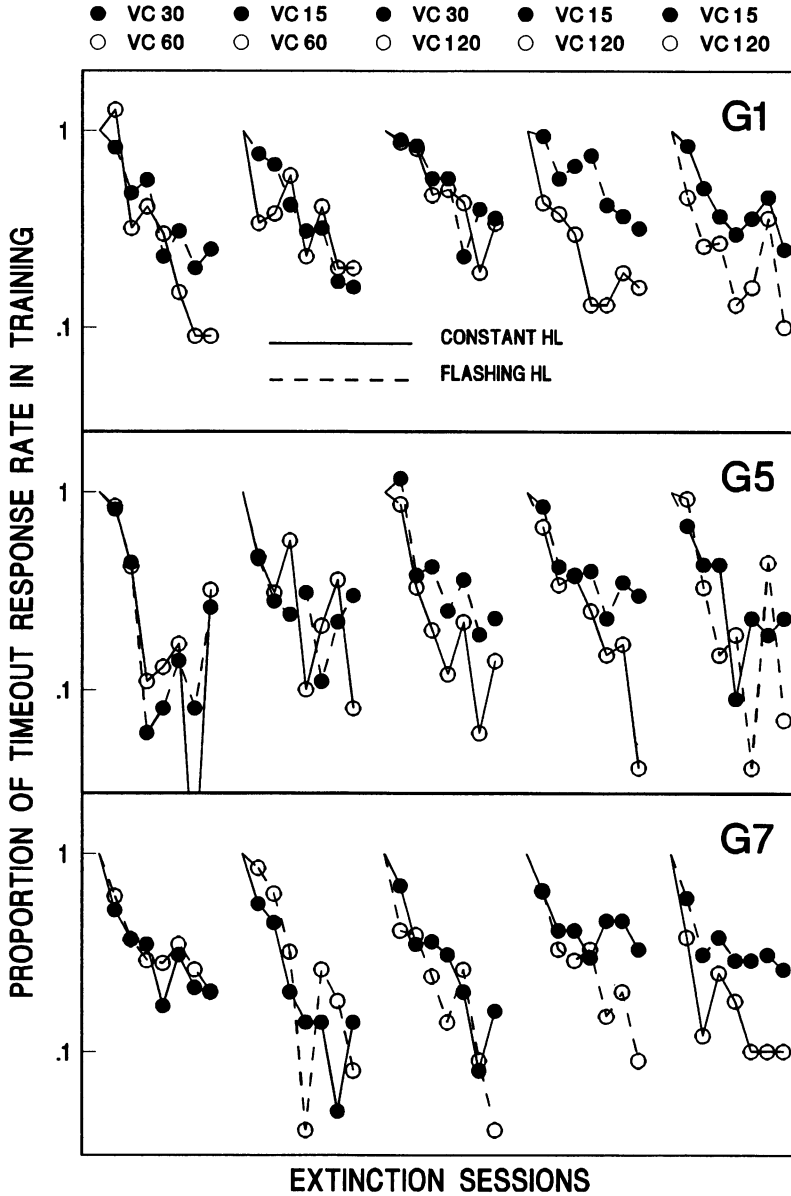


Fig. 3. Response rates on the timeout lever in the seven extinction sessions of each condition, expressed as a proportion of the mean rate of the last five training sessions. The origin of each function is the baseline proportion of 1.0.

measures of shock-frequency reduction. In the left panels, the measure is the rate of received shock during the avoidance schedule, because this represents the overall change in shock rate from time-in to timeout. The center panels substitute the scheduled shock rate as the measure of shock-frequency reduction. This analysis treats the timeout response as an alternative form of avoidance—one that reduces the shock rate from the scheduled value during

time-in to zero during timeout. With either measure, the outcome is about the same. For Rats G1 and G5 the slopes of the regression lines are slightly positive, and for G7 they are slightly negative. The lines appear to fit the data well, with most points falling on or near the lines, although the coefficients of determination are limited somewhat by the narrow range of the response ratios.

The right panel of Figure 2 shows the re-

lation between rates of responding on the timeout lever and concurrent responding on the avoidance lever. Because avoidance responses occurred almost exclusively in the presence of the multiple-schedule stimuli (99% of each rat's avoidance responses, averaged across conditions), this analysis allows assessment of sensitivity to the reduction in responding from the prevailing rate during time-in to a rate of essentially zero during timeout. Rats G1 and G5 showed a high degree of sensitivity to response reduction, with the slopes of the nearly perfect-fitting regression lines more than triple those of the previous analyses involving shock-frequency reduction. For Rat G7, however, there was no consistent pattern across conditions, and the slope of the regression line approached zero.

Extinction of Timeout Responding

Absolute rates of responding on the timeout lever are shown in Table 1, expressed as means over the last five training sessions but shown individually for each of the seven extinction sessions. Responding decreased over the course of the extinction phase, but comparison of the extinction rates across the two components is complicated by the fact that the training response rates differed. This problem was addressed by comparing relative response rates rather than absolute rates (Nevin, 1974). For each extinction session, the response rate in each component was divided by the mean rate in that component over the last five training sessions. The resulting relative rates are plotted on a logarithmic scale in Figure 3, with the conditions shown in order of increasing difference between the mean shock cycles in the two components. To show the change from the rate during training, each function originates at the relative baseline value of 1.0.

Large differences in the rate of extinction can be seen in only two or three conditions per rat. All 3 rats, however, show similar patterns in the first multiple VC 15-s VC 120-s condition (fourth set of functions in each rat's panel): Responding was more resistant to extinction in the VC 15-s component than in the VC 120-s component. This condition involved the most extreme contrast between the VC schedules—an eight-fold difference in scheduled shock rate. When the condition was replicated with a stimulus reversal (last set of functions), Rats G1 and G7 still had higher

Table 2

Slope and proportion of explained variance (r^2) of least squares regression lines fitted to the extinction functions in Figure 3. The lines are based on the relative response rates across eight periods: a baseline value of 1.0 and the proportion of the baseline value in each of the seven extinction sessions (all expressed as logs). The results are shown separately for each pair of components in the multiple variable-cycle variable-cycle (VC) schedules.

VC (s)	Rat G1		Rat G5		Rat G7	
	Slope	r^2	Slope	r^2	Slope	r^2
30	-0.098	.83	-0.125	.41	-0.088	.74
60	-0.169	.91	-0.151	.45	-0.081	.78
15	-0.118	.97	-0.076	.46	-0.154	.81
60	-0.076	.58	-0.113	.55	-0.156	.60
30	-0.078	.74	-0.104	.78	-0.131	.85
120	-0.088	.81	-0.149	.76	-0.165	.87
15	-0.069	.84	-0.076	.72	-0.049	.51
120	-0.108	.74	-0.167	.90	-0.129	.89
15	-0.072	.71	-0.104	.58	-0.068	.68
120	-0.101	.59	-0.147	.52	-0.122	.70

relative timeout rates in the VC 15-s component.

Table 2 summarizes the course of extinction by presenting the slopes of least squares regression lines fitted to the functions in Figure 3. By comparison with the graphs, this regression analysis permits the detection of more subtle differences across the schedule components. All of the slopes are negative, reflecting the reductions in responding over the seven extinction sessions. In 13 of the 15 conditions, the absolute value of the slope is smaller in the component with the shorter programmed intershock interval, reflecting greater resistance to extinction. The differences in the slopes are small, however, and the fits of the lines (r^2) are often modest.

Because programmed shock rates, received shock rates, and avoidance response rates were intercorrelated (cf. Figures 1 and 2), the differences across components in resistance to extinction (Figure 3 and Table 2) could be attributable to any of these factors, alone or in combination. To assess the relation between these factors and resistance to extinction, we calculated Pearson correlations between the shock and avoidance rates during the terminal training sessions, on the one hand, and the absolute values of the slopes of the extinction functions, on the other. The results are shown in Table 3. Although most of the correlations

Table 3

Pearson correlations (r) between the absolute values of the slopes of the extinction functions in Figure 3 and the training rates of programmed shock, received shock, and avoidance responding in the corresponding variable-cycle schedule component. Each coefficient is based on results from 10 components (two from each of the five conditions).

Rate (event/min)	Rat G1	Rat G5	Rat G7
Programmed shock	-.30	-.89	-.48
Received shock	-.25	-.83	-.38
Avoidance response	-.34	-.37	-.12

are modest in size, all are negative, indicating that increased shock and avoidance rates during training were associated with shallower slopes during extinction—that is, greater resistance to extinction. None of the training factors has a clear advantage in predicting the course of changes in timeout response rates during extinction.

DISCUSSION

Previous studies of responding on VC shock-deletion schedules have found that, with shock-frequency reduction as the measure of reinforcement, the relation between response and reinforcement rates conformed to the matching law (de Villiers, 1972, 1974; Logue & de Villiers, 1978). In the present experiment, too, avoidance behavior was directly related to variations in shock-frequency reduction (Figure 1), although the degree of sensitivity was somewhat less than that observed earlier. Identifying the basis for this difference will require additional research. It seems likely, however, that sensitivity was reduced in the present experiment by the low shock intensity we used (1.0 mA vs. 1.5–2.0 mA in de Villiers' laboratory) and by the fact that our subjects' avoidance behavior was frequently interrupted by responding on the concurrently available timeout lever.

Evidence for shock-frequency reduction as the reinforcer in simple avoidance situations, although open to criticism on theoretical grounds (e.g., Davison & McCarthy, 1988, p. 135; Dinsmoor, 1977, pp. 89–91), suggests at least the possibility that shock-frequency reduction may play a role in behavior maintained by timeout from avoidance. The present analysis, however, indicates that responding on the timeout lever was relatively insensitive to shock-

frequency reduction (left and center panels of Figure 2). This finding corroborates Perone and Galizio's (1987) results. In their experiment, timeout maintained rats' lever pressing even though the rates of shock-frequency reduction were low—usually less than 0.3 shocks per minute and sometimes less than 0.05. Because these rates are well below those in published demonstrations of reinforcement by shock-frequency reduction (e.g., reductions of about 0.6–3.6 shocks per minute: de Villiers, 1974; 3–9 shocks per minute: Herrnstein & Hineline, 1966), Perone and Galizio argued that it is unlikely that they played a major role in the reinforcing functions of timeout. By comparison with Perone and Galizio's research, the rates of shock-frequency reduction in the present study covered a much wider range. Expressed in terms of programmed rates, the range was 0.5 to 4.0 shocks per minute; in terms of received rates, the range was 0.07 to 2.54 for Rat G1, 0.06 to 2.42 for G5, and 0.05 to 1.22 for G7 (Table 1). Still, responding on the timeout lever was only weakly related to shock-frequency reduction.

Responding on the timeout lever was sensitive to variations in the rates of concurrent responding on the avoidance lever, at least in 2 of the 3 rats (right panels of Figure 2). With regard to the exceptional animal, Rat G7, it should be noted that the near-zero sensitivity parameter results from a single outlying data point (the one above the diagonal) that was obtained in the final stimulus-reversal condition. With that point omitted, the slope of the regression line rises to 0.91 ($r^2 = .70$). Furthermore, this experiment's ability to measure sensitivity is limited by the narrow range of rates of avoidance responses we managed to generate (note the scale in the right panels of Figure 2). Given this limitation, which would tend to obscure observation of sensitivity to variation in avoidance rates, it is remarkable that high degrees of sensitivity were in fact detected in the other 2 rats.

Although it remains possible that shock-frequency reduction makes some contribution to the reinforcing efficacy of timeout, the present findings suggest that a more potent factor is the temporary reduction in response effort associated with suspension of the VC shock-deletion schedules. By producing a timeout, the rat escapes a contingency that engenders sustained responding and enters an alternative

situation with no response requirement. Evidence that responding can be aversive is found in the literature on positive reinforcement. Several studies, for example, have identified circumstances in which pigeons and rats will escape from fixed-ratio schedules leading to food (e.g., Azrin, 1961; Thompson, 1964). More direct evidence comes from Grossbard and Mazur's (1986) experiment, in which pigeons could gain access to food through either response-dependent (fixed-ratio) or response-independent (fixed-time) schedules adjusted so that the average delay to food did not differ across the alternatives. The pigeons preferred the response-independent schedule; in other words, they chose a situation in which food could be obtained without responding over one in which food depended on responding. Grossbard and Mazur's results bear resemblance to the outcome of the present study, in which rats preferred a shock-free period without responding (timeout) over a situation in which freedom from shock depended on sustained responding (the VC schedule during time-in). Viewed this way, the findings support Hineline's (1984) suggestion that the aversiveness of a behavioral situation may well depend on a range of events (or relations among events) in addition to primary stimuli such as shock.

To say that the reinforcing function of timeout derives from reductions in response effort is not to say that responding on the timeout lever reduces the *overall* effort expended during a session. Because our procedure kept the VC shock-deletion schedules in effect for a constant 50 min per session, even frequent timeout production could yield no savings in the number of responses needed to minimize receipt of shock. Responding on the timeout lever did, however, lead to *local* reductions in effort by suspending the avoidance contingency for 2 min.

Another way to explain the reinforcing efficacy of timeout might point to the correlation between responding on the avoidance and timeout levers as an instance of response generalization: When conditions are such that high or low rates are established on the avoidance lever, these high or low rates may generalize to the timeout lever. Arguing against this idea are results of experiments showing that timeout response rates can be raised or lowered independently of avoidance rates, either by manipulating the schedule associated with the

timeout lever (Galizio & Allen, 1991; Perone & Galizio, 1987), by changing the duration of the timeout periods (Posner & Baron, 1981), or by administering drugs that affect timeout and avoidance behavior differentially (Galizio & Allen, 1991; Galizio et al., 1986, 1990; Galizio & Perone, 1987).

Unlike the matching analysis of the data from the terminal training sessions, analysis of the extinction data did not identify different contributions of shock-frequency reduction and reduction of avoidance responding to resistance to change (Table 3). The relation between steady-state responding on the avoidance and timeout levers suggests that the extinction data also may reflect a contribution of avoidance response reduction to the strength of timeout responding. Another possibility, however, is that control of the strength of timeout-maintained behavior varies across training and extinction conditions. Reduction in avoidance response rates may dominate shock-frequency reduction in the maintenance of timeout responding, whereas these factors may contribute more equally to resistance to extinction. Additional research is needed to decide the matter. To study directly the role of avoidance response reduction, for example, the avoidance schedules in the two components would have to maintain consistently different rates of avoidance responding while providing similar shock rates. If different extinction gradients were obtained in such a case, they could be more clearly attributed to the contribution of reduced avoidance responding in the reinforcing effectiveness of timeout.

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